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Improving the Performance of Fire Retardant Delivery Systems on Fixed-Wing Aircraft

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ABSTRACT

Studies of the performance of fire retardant delivery systems for fixed-wing aircraft have indicated that performance can be significantly improved by modifying delivery systems to allow the selectable and controllable flow of retardant from the tank. The report describes several concepts in improving delivery system performance and Interagency Airtanker Board (IATB) criteria for achieving these improvements. Other requirements for implementing the concept are also discussed.

KEYWORDS: *wildland fire, fire management, aerial attack, chemical retardant, airplane*

Since use of fixed-wing aircraft in forest firefighting became an accepted practice late in the 1950's, little specific guidance from fire management agencies has been provided to operators as to how the delivery systems should perform. Agencies have specified retardant capacities, gross weight, wheel loading, flight speed, and various other aircraft characteristics. These have generally been dictated by airport runway, taxiway, ramp, retardant base, or other limitations. The actual performance of the delivery system has been for the most part a result of the creativity of owner/operators and their tank designers.

The constraints of the aircraft fuselage, structure, etc., have often dictated design of delivery systems.

Although performance of the delivery system has not been entirely ignored the need for simplicity and reliability has been a major influence. Fire managers did not have the ability to provide quantitative data on how much retardant chemical or water is required in given fuel and fire situations nor what the upper and lower limits for effectiveness were. How wide should the retardant line be, and what kinds of line increments were most desirable? In addition, the information needed to relate tank and release characteristics with actual retardant ground distribution patterns was not available. In other words, operators, by trial and error, experience, and assessment, developed delivery systems to meet agency desires. As a result, numerous delivery systems for a variety of aircraft types evolved. Little standardization resulted. Performance varied. Some systems were found to be fairly versatile, others were found to be effective only in specific situations and sometimes regional conditions. (Figure 1 shows the variability in line-building capability of a few selected airtanker delivery systems.) The efficiency of these airtankers in building fireline varies considerably with coverage level. For a number of reasons, operators have often failed to be rewarded for producing "better," "more flexible," "more efficient," or "advanced" delivery systems.

There have been in recent years, however, attempts by agencies to describe the desired performance of airtankers and provide various types of information aimed at improving the effectiveness of airtanker delivery systems. These have included tank design guidelines, performance guidelines and retardant coverage slide-chart computers, and minimum performance criteria that could be used in a process to qualify new delivery systems. This report describes progress made to date and opportunities to make further improvements.

ESTABLISHING THE AIRTANKER BOARD AND THE IMPROVEMENT PROGRAM

One of the first attempts to improve the performance and safety of airtankers began with the

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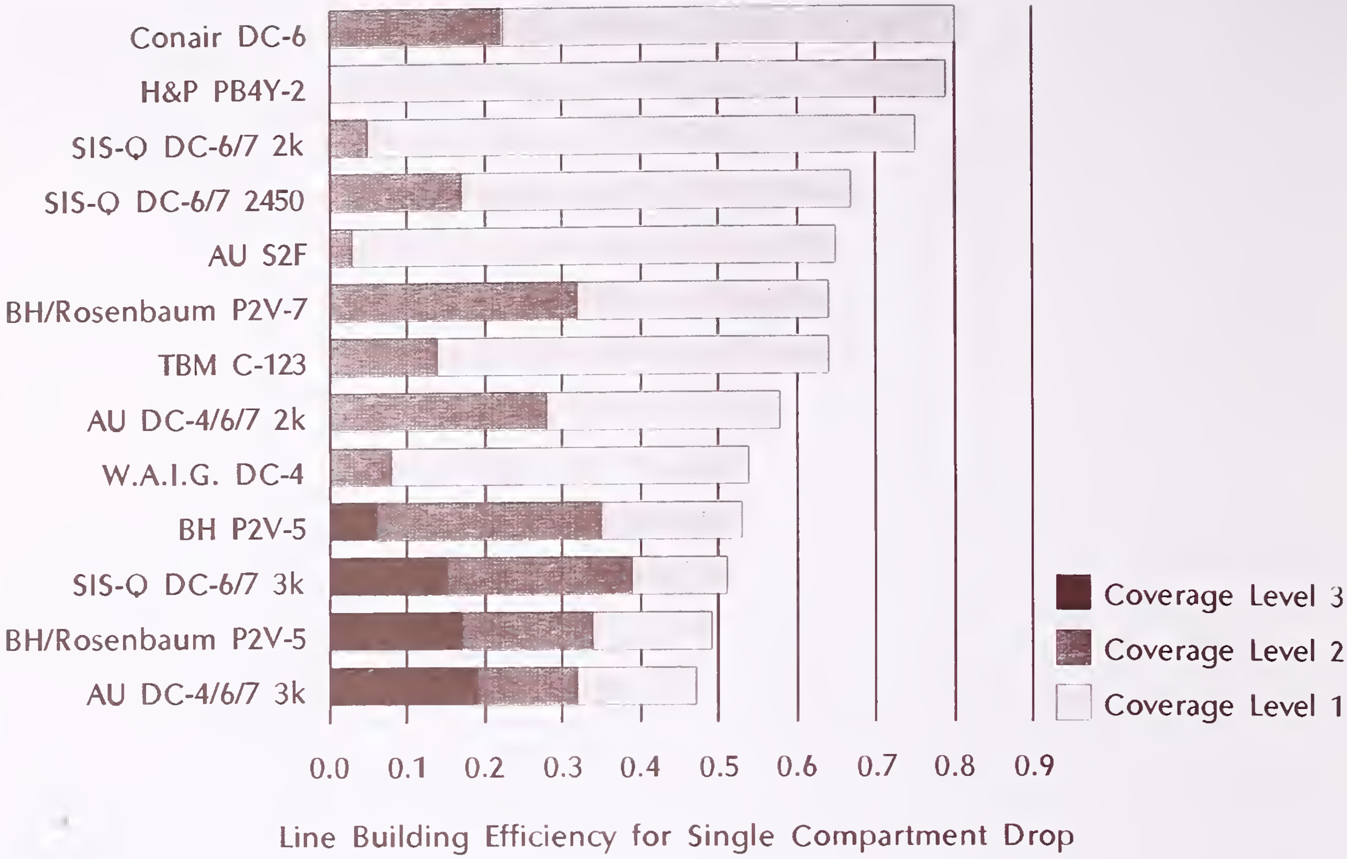


Figure 1—A comparison of the line-building efficiency (feet of line per U.S. gallon of retardant) of single tank drops at coverage level 1, 2, and 3 (gallons per 100 square feet) for a selection of different airtanker delivery systems.

formation of an Airtanker Board (ATB) by the U.S. Forest Service in 1970 (industry participated as a full member of this board). The board was formed to meet the need for assessing new aircraft and tank and gating systems that were being proposed to the Forest Service and other fire management agencies. In 1977 the board took on an interagency role with the additional membership of the Department of the Interior, Office of Aircraft Services (OAS), the Association of State Foresters, and a revised charter. The objectives of the newly formed Interagency Airtanker Board (IATB) were:

1. Accept, review, evaluate, and recommend new or modified airtankers.
2. Act as advisor to agencies and industry operators in overall improvement of airtanker delivery systems.
3. Provide a vehicle for cooperative studies in the development, screening, and selection (R&D) of new airtankers.
4. Promote improvement in effectiveness and efficiency by integrating advancements of retardant technology into aerial delivery systems.
5. Provide a central source of data and information regarding testing, performance, and selection.

Since its establishment in 1970, one of the board's primary functions has been to set baseline or minimum requirements for airtankers, focusing on aircraft and delivery system performance. These minimum requirements are used to derive a list of "approved airtankers" that are qualified to respond to member agency tenders. Actual contract specifications prepared by user agencies contain a requirement that airtankers must be "approved by the board" as well as other specific user requirements. Figure 2 illustrates the interaction of the IATB approvals and agency needs and specifications.

Initial performance standards were developed around the performance of the existing fleet of aircraft being used by fire management agencies. These standards were written based on a consensus that new aircraft must be "equal or better" in terms of performance than airtankers in the existing fleet. To develop these standards and criteria, current knowledge gained from recent research, development, and evaluation programs was heavily drawn upon. Approval processes were established that contained: (1) a grandfather provision to cover airtankers that were operating at that time; (2) procedures for new airtankers;

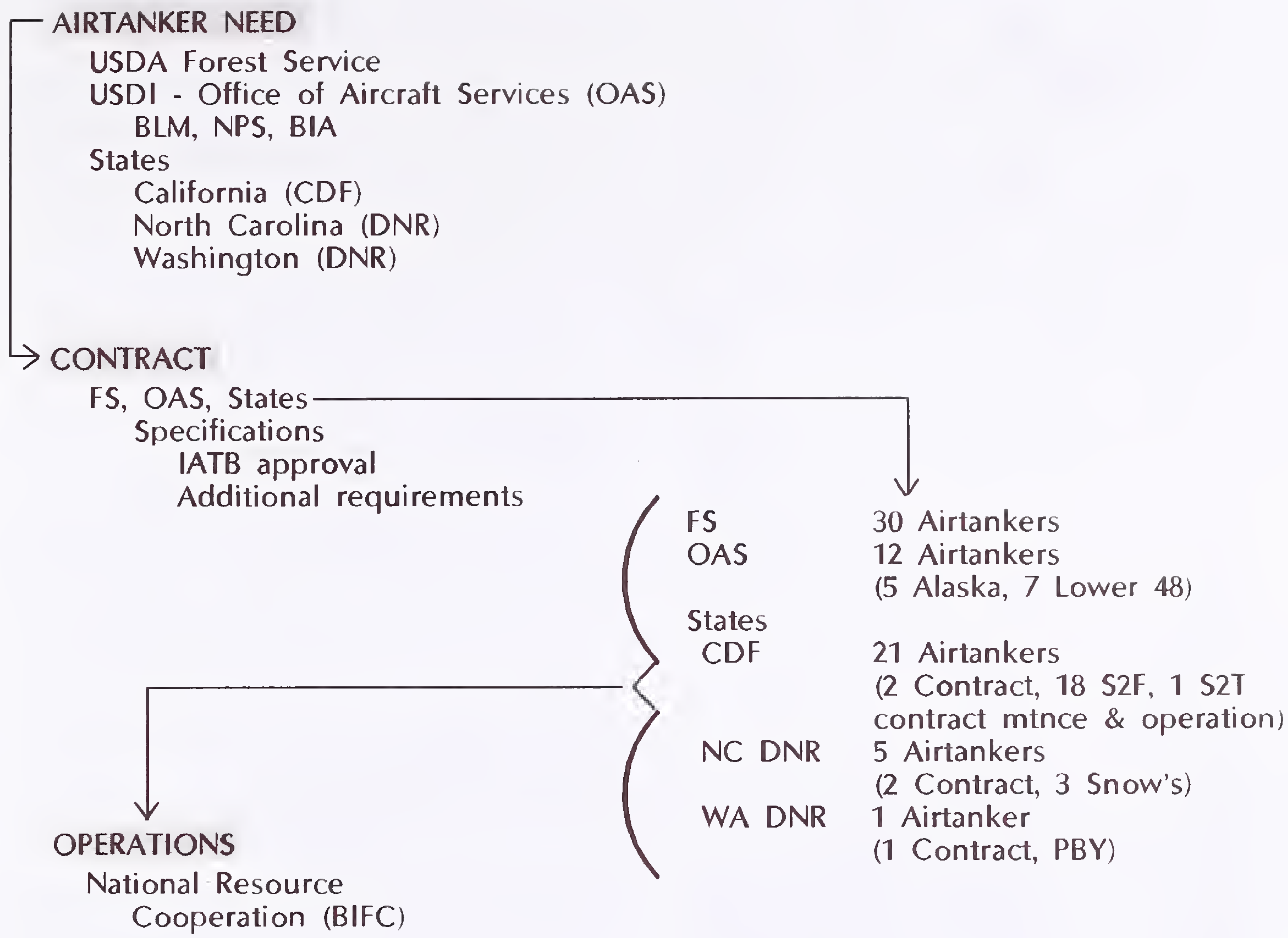


Figure 2—Interaction of Interagency Airtanker Board approvals and agency needs and specifications.

(3) procedures for additional airtankers of identical type and having similar tank and gating system; and (4) procedures for modification of approved airtankers. The operation of the board, application and processing of aircraft, and the criteria, although undergoing continual change, have been outlined in numerous editions of ATB and IATB procedures and criteria documents (USDA FS 1987).

DELIVERY SYSTEM IMPROVEMENT PROGRAM

Delivery System Research

The evaluation of the performance of the delivery systems revolves around research studies initiated by the Forest Service in 1969 to quantify the capabilities of different tank and gating systems. The studies entailed the dropping of retardant and/or water over a sampling grid and determining the ground pattern under a variety of conditions: tank configuration, door sequencing speed, drop height, retardant type, relative humidity, temperature, windspeed, and direction (George 1975; George and Blakely 1973). Using these data, Honeywell Corporation,[2] under contract to the Forest Service, developed a pattern simulation model with flow history from the individual systems being the primary variable (Swanson and others 1975). Figure 3 shows the relationship between ground distribution patterns and the characteristics of retardant flow from the tank system. The initial model used flow history derived from motion pictures of airborne airtanker drops. The pattern simulation model (PATSIM) was refined through the use of accurately measured flow data (Swanson and others 1977) and is illustrated in figure 4. With better understanding of retardant breakup, cloud formation, and ground distribution of retardant, additions and modifications to the

[2]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

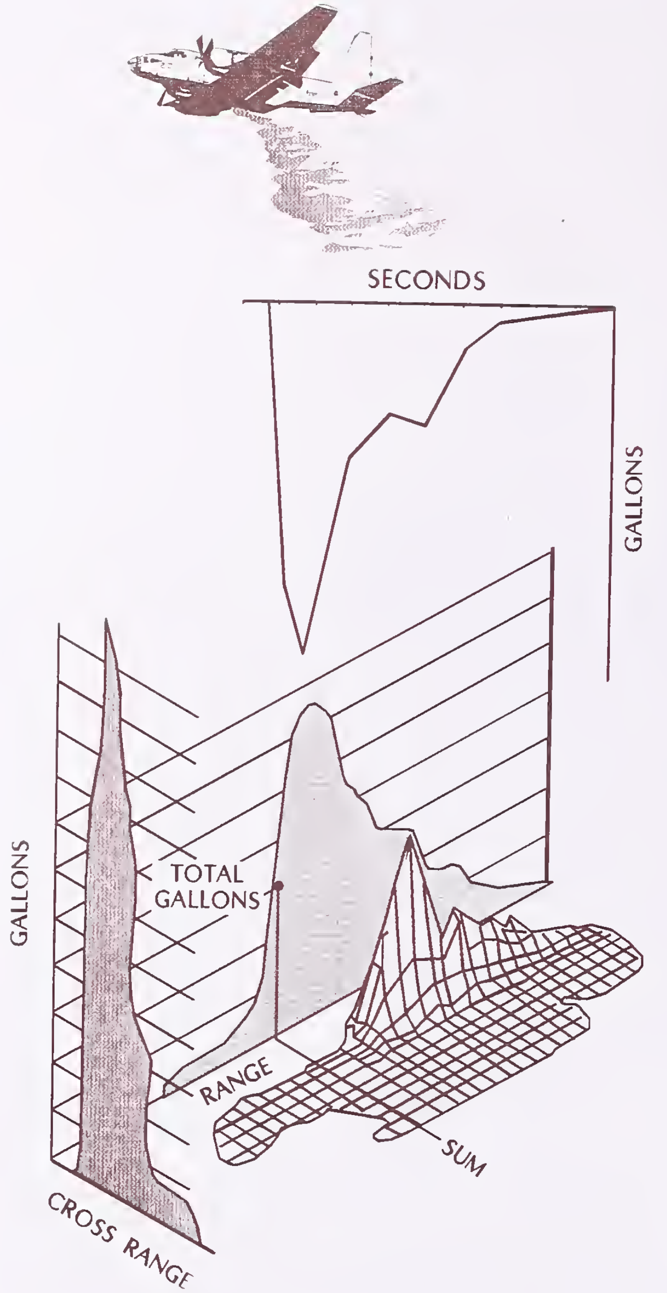


Figure 3—Relationship between ground distribution patterns and characteristics of retardant flow from the tank system.

model/models have been made and documented (George and Johnson 1990; George 1981). Methods of measuring and interpreting the data have similarly been defined (Blakely and others 1982). Output from the models has been used in the development of airtanker performance guides and retardant coverage computer/slide charts (George 1981), a tank design guide for fire retardant aircraft (Swanson and Luedecke 1978), guidelines for estimating the effects of downloading (Luedecke and Swanson 1979), and criteria for use in establishing new airtanker requirements.

Airtanker Performance Requirements

The first airtanker performance requirements (established by the Airtanker Board) for new airtankers were developed using the performance of airtankers being used at that time and the "equal to or better approach." Figure 5 shows the first established requirements (flow rate versus tank volume) for delivery systems and the performance provided by a sample of existing airtankers. The number of points defining the flow rate/load or drop size relationship determines the number of types of release possible and the overall flexibility of the delivery system. The performance of these airtankers was categorized depending on the flow rate of retardant from their tanks—high, moderate, low, and prolonged. Because the retardant flow rate and volume of drop determines the ground pattern distribution and coverage level, a general relationship was identified and is shown in figure 6. In addition, these coverage levels and flow rates have been recommended for the various fuel and fire behavior models (fig. 7). It should be noted here that retardant coverage level has been expressed as gallons per hundred square feet (gpc), and depth (inches or centimeters). A coverage level of 1, 2, 3, or 4 refers to 1, 2, 3, or 4 gallons per hundred square feet.

Improved Performance Requirements

With knowledge of these relationships and the performance of airtankers presently in use, the flexibility and performance of individual airtankers, as well as the entire fleet, could be enhanced by incorporating in each airtanker the ability to regulate the flow rate of retardant during release. With this goal in mind, in 1986 the IATB developed performance criteria that would require a variety of flow rates to be produced by each airtanker. These criteria would thus require modification of existing airtankers to control flow rate in a prescribed manner, depending on the airtanker's retardant capacity, the number of compartments, and the volume of each. Figure 8 depicts the flow rate performance that would be required for each airtanker, utilizing drop configuration (singles, doubles, etc.), and release sequence (release interval for multicompartment tanks). Several approaches to regulating flow rate are possible. One method is shown in figure 9. To accommodate other approaches, evaluation methods were written so as to allow actual drop tests to be used to demonstrate that specified ground coverage levels and pattern lengths could be attained with other than conventional retardant delivery systems. Figure 10 provides an example of a controllable continuous-flow Aero Union SP-2H system, designed to achieve control of flow from a single tank/door system.

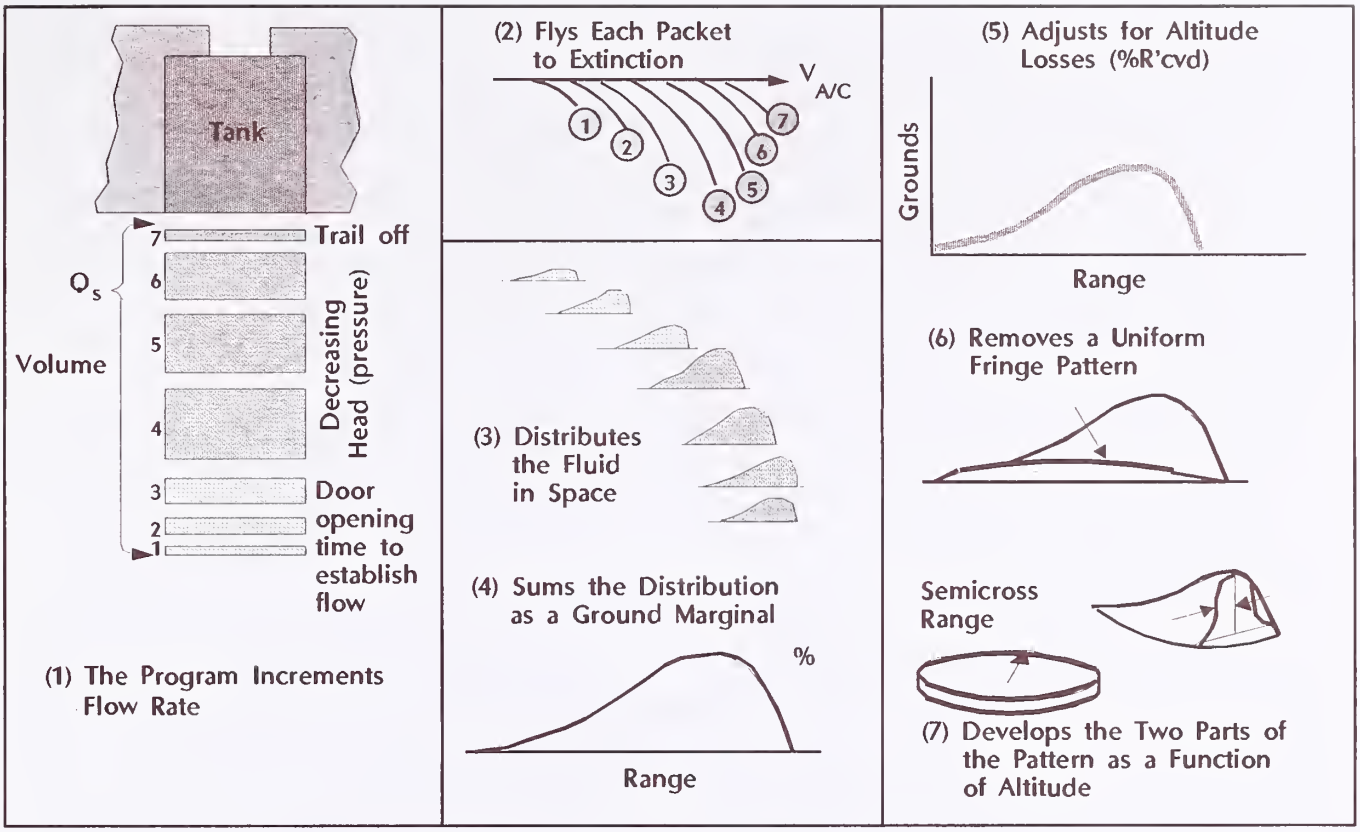


Figure 4—Pattern simulation model (PATSIM) used to predict ground distribution patterns from retardant release characteristics.

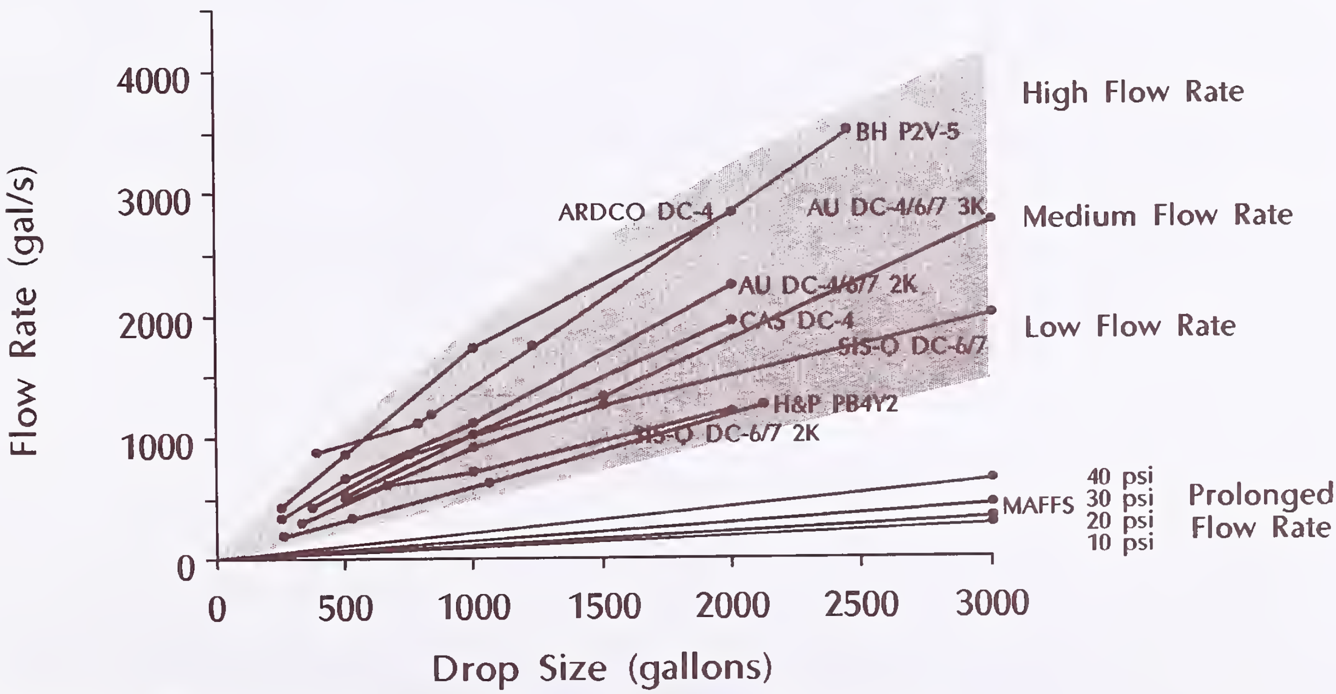


Figure 5—Comparison of the flow rate requirements (shaded area) and the performance of several selected airtankers.

Retardant Coverage Level [1] (gal/100 ft^2)	Flow Rate Range (gal/s)
1	100-150
2	151-250
3	251-400
4	401-600
6	601-800
Greater than 6	Greater than 800

[1] Coverage Level, gallons/100 ft^2, and gpc are often used synonymously.

Figure 6—Flow rate required to produce selected retardant coverage levels.

Fuel Model NFDRS	Fuel Model FB	Coverage Level (gal/100 ft^2)	Flow Rate Range (gal/s)	Description
A,L,S	1	1	100-150	Annual & Perennial Western Grasses; Tundra
C H,R E,P,U	2 8 9	2	151-250	Conifer with Grass Shortneedle Closed Conifer; Summer Hardwood Longneedle Conifer; Fall Hardwood
T N F K	2 3 5 11	3	251-400	Sagebrush with Grass Sawgrass Intermediate Brush (green) Light Slash
G	10	4	401-600	Shortneedle Conifer (heavy dead litter)
O F,Q	4 6	6	601-800	Southern Rough Intermediate Brush (cured); Alaska Black Spruce
B,O J I	4 12 13	Greater than 6	Greater than 800	California Mixed Chaparral; High Pocosin Medium Slash Heavy Slash

Figure 7—Retardant flow rate range and coverage level recommended for NFDRS fuel and fire behavior models.

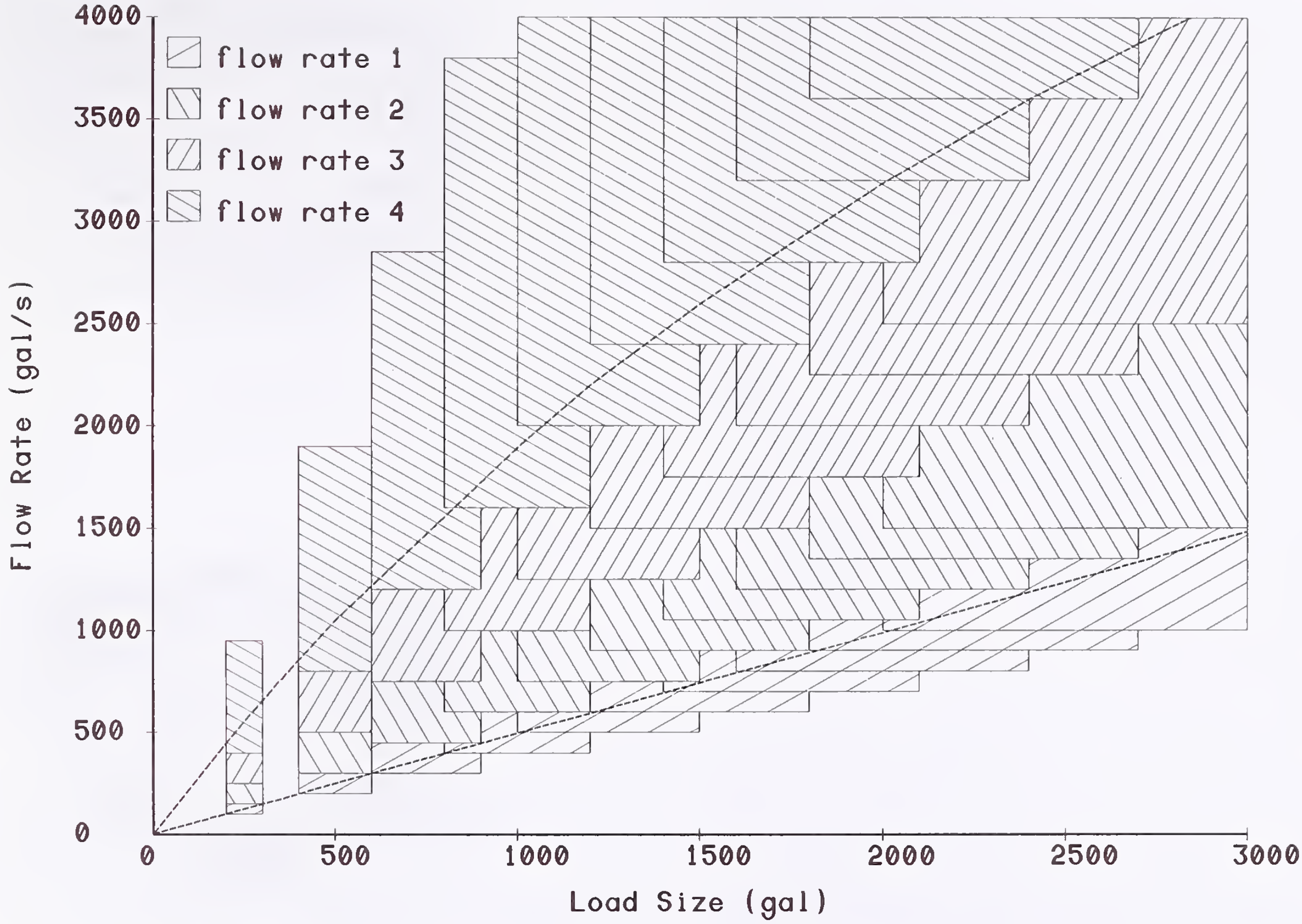


Figure 8—Example of the multiple flow rates that are required by the new IATB criteria for various release volumes.

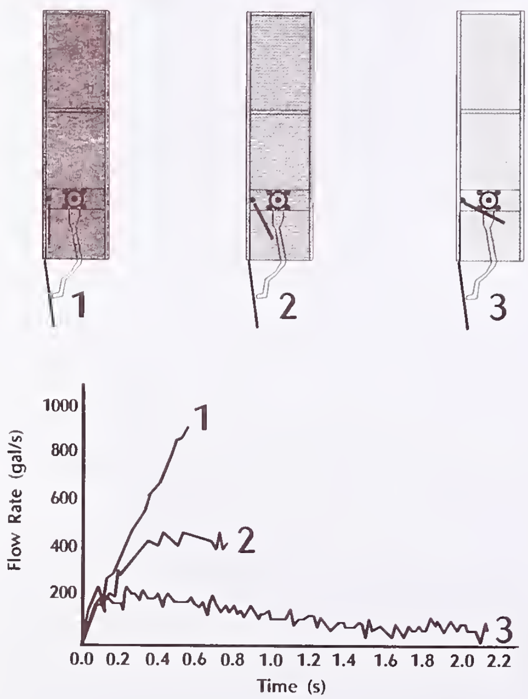


Figure 9—Example of one approach to achieving variable flow rate in a conventional tank.

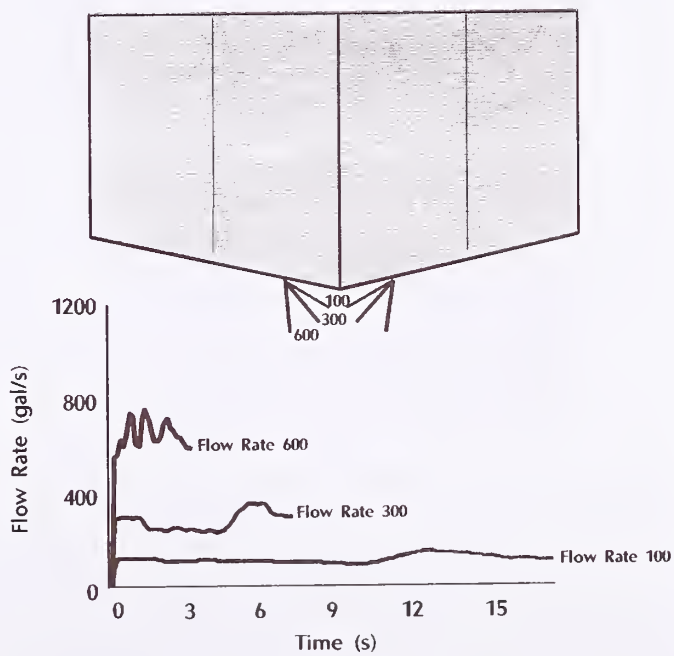


Figure 10—Example of a "controllable continuous flow" Aero Union SP-2H system.

To implement the improved IATB delivery system criteria developed in 1986, considerable time and effort would be required. Modification of many of the existing airtankers in the fleet was anticipated, while the new concepts would more likely be added to new aircraft joining the fleet. With this in mind the IATB set 1990 as the date for implementation, and the improved criteria became known as the "1990 criteria." In late 1989 and early 1990, however, it became apparent that, although private industry was moving to incorporate the new performance requirements, actual implementation in 1990 was overly optimistic. Several systems aimed at meeting the 1990 criteria were developed and placed in service by or before 1990, however, and were fairly successful in demonstrating the flexibility of the new systems (KC-97, C-130, and SP-2H). These new and improved systems are generally getting good reviews, and better acceptance can be expected with increased familiarity with the systems by those involved in their application, including airtanker crews, air attack supervisors, etc.

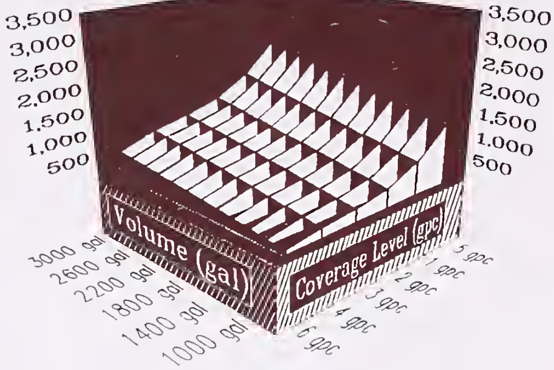
Comparative System Performance

The new systems demonstrated improved efficiency (length of line per gallon of retardant) at the various coverage levels over older unimproved designs. Figure 11 shows the relative performance improvements of the new improved systems against the older unimproved systems at different coverage levels. Tables 2 and 3 in the appendix provide line production values (feet of line per 100 gallons and total line length per aircraft load) for the old and new improved systems. A comparison of line length capabilities of unimproved and improved airtankers at 1,000, 2,000, and 3,000 gallons is shown in table 1.

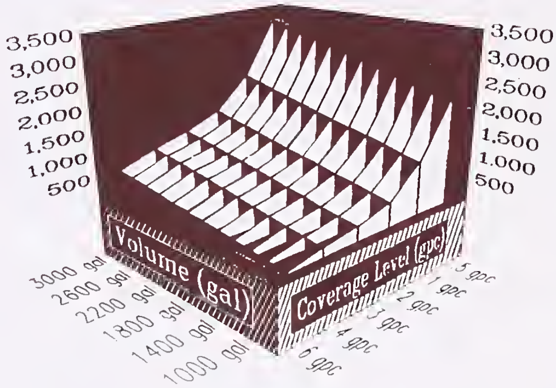
The average percent improvement of airtankers meeting the 1990 IATB criteria for coverage levels 0.5 to 4.0 (gal/100 ft^2 or gpc) is as follows:

Coverage	**Improvement**
gpc	*Percent*
0.5	57
1	42
2	21
3	12
4	5

Figures 12 and 13 show the performance of a modified conventional tank in a Black Hills P2V airplane (using single and sequential drops). Flow rates in the P2V are achieved by combining the flow from six compartments, each containing a flow restrictor that can be used to provide a second flow rate. By use of these flow rate combinations and the manner in which they are sequenced, several flow



Unmodified Airtankers



Modified Airtankers

Figure 11—Line length prediction curve for new systems.

Table 1—Comparison of line length (ft) capabilities of improved and unimproved airtankers

Item	Coverage level (gpc) 0.5	1	2	3	4
			1,000 gallons		
Unimproved	1,374	793	473	340	254
Improved	2,337	1,202	607	384	255
Percent improvement	70	52	28	13	0
			2,000 gallons		
Unimproved	1,806	1,205	846	674	547
Improved	2,794	1,640	1,009	751	586
Percent improvement	55	36	19	11	7
			3,000 gallons		
Unimproved	2,239	1,618	1,219	1,008	843
Improved	3,250	2,078	1,411	1,117	916
Percent improvement	45	28	16	11	9

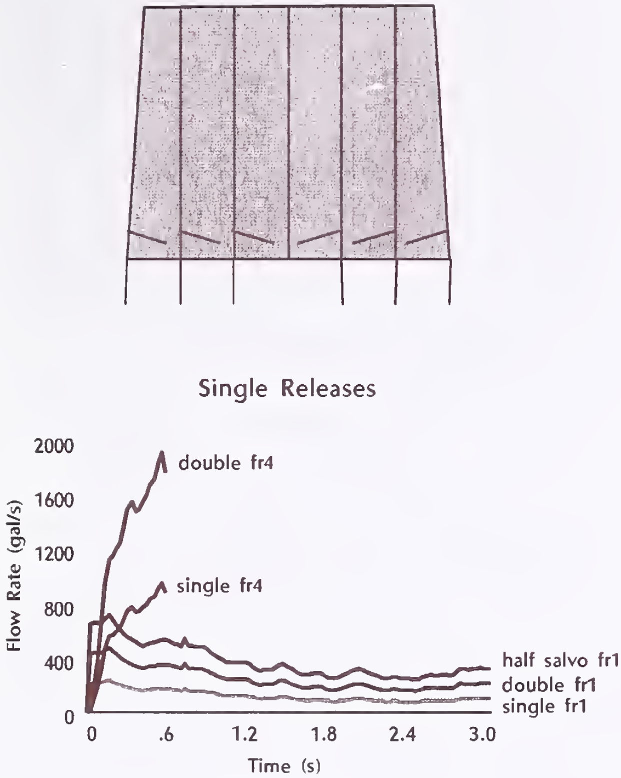


Figure 12—Flow rate performance for controlled releases from a six-compartment conventional tank (Black Hills P2V).

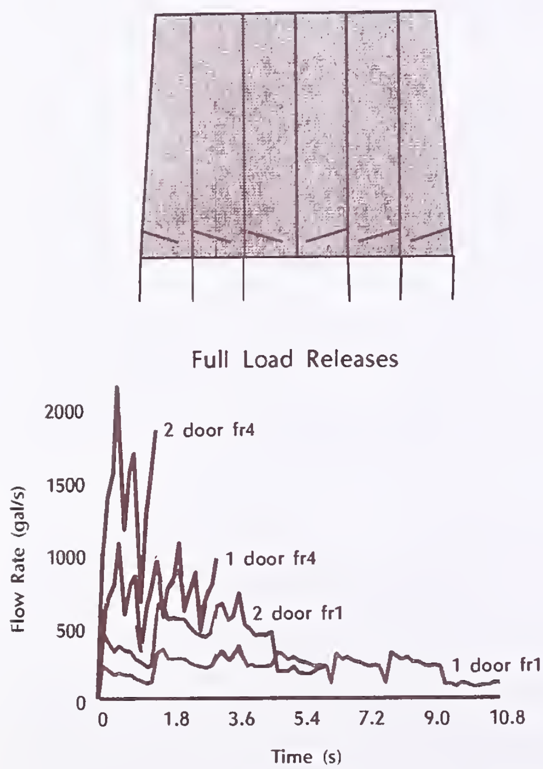


Figure 13—Flow rate performance for sequential restricted flow releases from a six-compartment conventional tank (Black Hills P2V).

rates can be obtained as shown in the composite of the P2V's performance in figure 14. Figure 15 shows the performance of a TBM, Inc., C-130 airplane (Aero Union, Inc. tank) controllable continuous-flow system. (The C-130 system is similar in concept to the SP-2H tank system illustrated in figure 10, but it has a vastly different tank shape.) The flow is varied by controlling the speed and degree at which two synchronized doors are opened, and adjusting that opening to attain a linear flow rate. A composite of its performance capabilities is shown in figure 16. Although further quantification of the two different approaches to controlling flow rate is necessary, the "controllable continuous flow" approach seems to produce the most line length per gallon.

The new performance criteria will probably be implemented over the next several years. Design and construction of new delivery systems or modification of existing delivery systems is only the first step in attaining improved performance and flexility. Control systems that simplify selection of flow control or retardant coverage might logically be the next essential step in the development. A new approach to selecting the type of drop should be considered by air attack supervisors, lead plane pilots, and others instrumental in applying fire retardant. The emphasis logically should be placed on the "retardant coverage level" for the specific fuel/fire situation. After deciding the appropriate coverage level, the air attack coordinator would notify the airtanker pilot/crew, who would simply select that level from his system control/display. Figure 17 illustrates the simplicity required for selecting the type of drop and "retardant coverage level" and the input/output needs for the tank system controls.

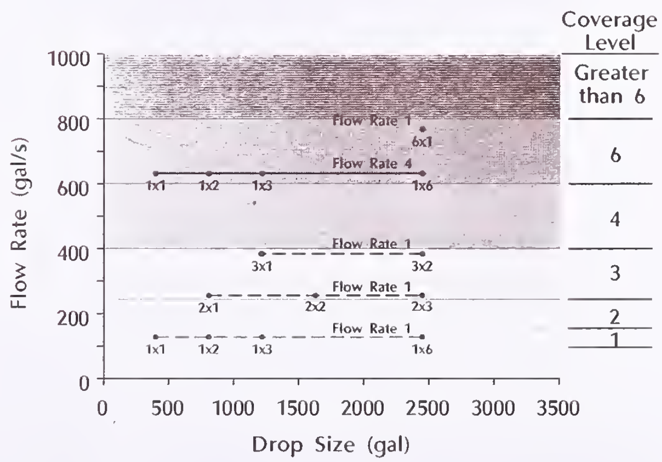


Figure 14—Graph showing a composite (from figures 12 and 13) of the performance capabilities of a six-compartment conventional tank (Black Hills P2V).

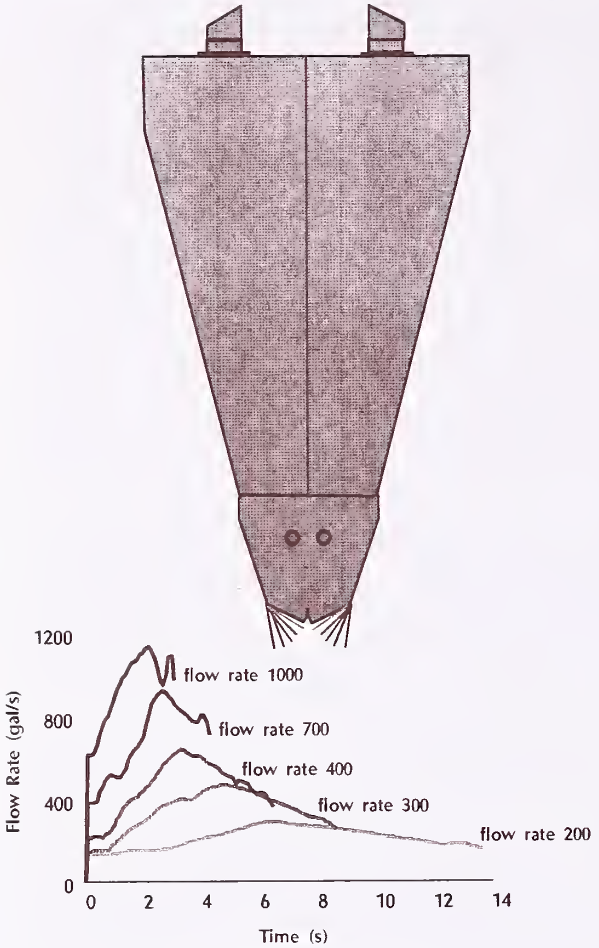


Figure 15—Flow rates produced by the controllable continuous-flow Aero Union tanked TBM Inc. C-130.

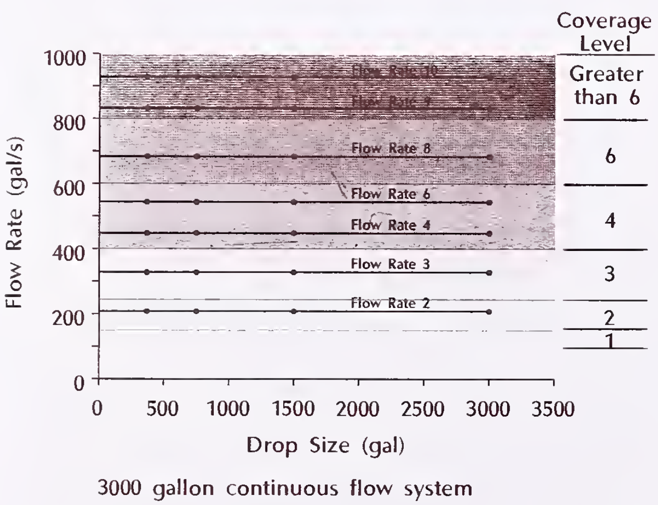


Figure 16—Graph showing the performance capabilities of the TBM C-130 with Aero Union tank.

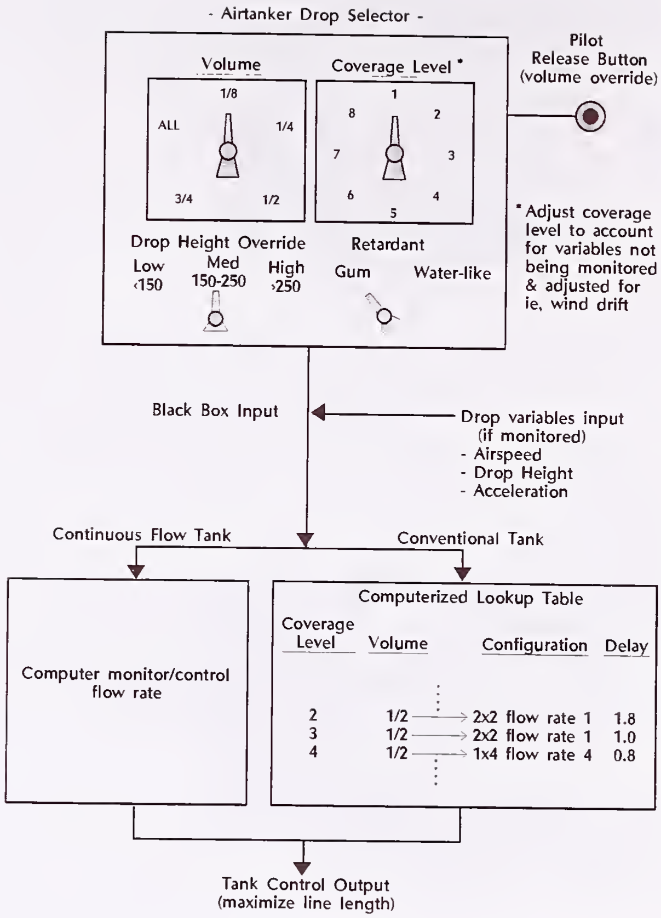


Figure 17—Example of a possible airtanker drop selector for conventional or continuous-flow delivery system.

CONCLUSIONS

Applying existing knowledge and technology available to the problem of aerial retardant delivery and fire suppression, using the method and process briefly described or some similar approach, should result in: (1) improved performance; (2) increased flexibility; (3) increased efficiency; (4) more consistent results; and (5) greater overall fire suppression capability, thus maximizing the effectiveness of each gallon of retardant delivered to the fire.

REFERENCES

Blakely, Aylmer D.; George, Charles W.; Johnson, Gregg M. 1982. Static testing to evaluate airtanker performance. Gen. Tech. Rep. INT-78. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 17 p.

George, C. W. 1975. Fire retardant ground distribution patterns from the CL-215 air tanker. Res.

Pap. INT-165. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 67 p.

George, Charles W. 1981. Determining airtanker delivery performance using a simple slide chart-retardant coverage calculator. Gen. Tech. Rep. INT-113. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

George, C. W.; Blakely, A. D. 1973. An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. Res. Pap. INT-134. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 60 p.

George, Charles W.; Johnson, Gregg M. 1990. Developing air tanker performance guidelines. Gen. Tech. Rep. INT-268. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 96 p.

Luedecke, A. D.; Swanson, D. H. 1979. Adjustments to basic airtanker performance guides to account for downloading. Honeywell Contract 786-2031-76 to Intermountain Forest and Range Experiment Station. 39 p.

Swanson, D. H.; Luedecke, A. D.; Helvig, T. N. 1978. Experimental tank and gating system (ETAGS). Final report. Honeywell Contract 26-3245 to Intermountain Forest and Range Experiment Station. 284 p.

Swanson, D. H.; Luedecke, A. D.; Helvig, T. N.; Parduhn, F. J. 1975. Development of user guidelines for selected retardant aircraft. Final report. Honeywell Contract 26-3332 to Intermountain Forest and Range Experiment Station. 154 p.

Swanson, D. H.; Luedecke, A. D.; Helvig, T. N.; Parduhn, F. J. 1977. Supplement to development of user guidelines for selected retardant aircraft. Final report. Honeywell Contract 26-3332 to Intermountain Forest and Range Experiment Station. 88 p.

U.S. Department of Agriculture, Forest Service. 1987. Interagency Airtanker Board, Spec. Rep. 8757 1801. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Equipment Development Center. 30 p.

APPENDIX—LINE PRODUCTION CAPABILITIES FOR UNIMPROVED AND IMPROVED AIRTANKERS

Table 2—Line production values in feet for unimproved airtankers as a function of coverage level and airtanker volume. (Numbers in parentheses are line length/100 gallons)

	Coverage level						
Volume	0.5	1	2	3	4	6	8
Gallons				*gpc*			
800	1,288	710	398	273	195	85	0
	(161)	(89)	(50)	(34)	(24)	(10)	(0)
1,000	1,374	793	473	340	254	128	26
	(137)	(79)	(47)	(34)	(25)	(13)	(3)
1,200	1,460	875	547	407	313	172	54
	(122)	(73)	(46)	(34)	(26)	(14)	(5)
1,400	1,547	958	622	473	372	215	82
	(111)	(68)	(44)	(34)	(27)	(15)	(6)
1,600	1,600	1,040	697	540	431	258	109
	(100)	(65)	(44)	(34)	(27)	(16)	(7)
1,800	1,720	1,123	771	607	490	301	137
	(96)	(62)	(43)	(34)	(27)	(17)	(8)
2,000	1,806	1,205	846	674	549	345	164
	(90)	(60)	(42)	(34)	(27)	(17)	(8)
2,200	1,893	1,288	921	741	608	388	192
	(86)	(59)	(42)	(34)	(28)	(18)	(9)
2,400	1,979	1,370	995	808	666	431	219
	(82)	(57)	(41)	(34)	(28)	(18)	(9)
2,600	2,066	1,453	1,070	874	725	475	247
	(79)	(56)	(41)	(34)	(28)	(18)	(10)
2,800	2,152	1,535	1,145	941	784	518	275
	(77)	(55)	(41)	(34)	(28)	(19)	(10)
3,000	2,239	1,618	1,219	1,008	843	561	302
	(75)	(54)	(41)	(34)	(28)	(19)	(10)

Table 3—Line production values in feet for improved airtankers as a function of coverage level and airtanker volume. (Numbers in parentheses are line length/100 gallons)

Volume	Coverage level 0.5	1	2	3	4	6	8
Gallons	*gpc*						
800	2,246	1,114	526	311	189	38	0
	(281)	(139)	(66)	(39)	(24)	(5)	(0)
1,000	2,337	1,202	607	384	255	90	0
	(234)	(120)	(61)	(38)	(26)	(9)	(0)
1,200	2,429	1,289	687	458	321	142	9
	(202)	(107)	(57)	(38)	(27)	(12)	(1)
1,400	2,520	1,377	768	531	387	194	46
	(180)	(98)	(55)	(38)	(28)	(14)	(3)
1,600	2,611	1,465	848	604	454	245	84
	(163)	(92)	(53)	(38)	(28)	(15)	(5)
1,800	2,702	1,552	929	678	520	297	121
	(150)	(86)	(52)	(38)	(29)	(17)	(7)
2,000	2,794	1,640	1,009	751	586	349	158
	(140)	(82)	(50)	(38)	(29)	(17)	(8)
2,200	2,885	1,728	1,090	824	652	400	196
	(131)	(79)	(50)	(37)	(30)	(18)	(9)
2,400	2,976	1,815	1,170	897	718	452	233
	(124)	(76)	(49)	(37)	(30)	(19)	(10)
2,600	3,068	1,903	1,251	971	784	504	270
	(118)	(73)	(48)	(37)	(30)	(19)	(10)
2,800	3,159	1,991	1,331	1,044	850	556	308
	(113)	(71)	(48)	(37)	(30)	(20)	(11)
3,000	3,250	2,078	1,411	1,117	916	607	345
	(108)	(69)	(47)	(37)	(31)	(20)	(12)

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